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# Comparison of the differential mode against the coherent mode in G3-PLC

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**Abstract**—In 2013, the updated version of G3-PLC was released. This new version proposes the possibility to choose between a differential and a coherent mode for the physical layer. In [4], PRIME and the differential mode of G3-PLC physical layer are discussed to make a decision for IEEE 1901.2. This standard has been released and includes the physical layer of G3PLC, both the differential as the coherent mode. This paper will compare the two different modes for G3-PLC in the CENELECA band.

## I. INTRODUCTION

At the end of 2013, IEEE released its newest standard for Narrowband Powerline Communication(NBPLC): IEEE 1901.2[1]. This standard adapted the physical layer of G3PLC. Both a coherent mode and a differential mode are in the novel IEEE standard. This physical layer was chosen because of its robustness. This paper will compare the performance of both modes and will check in which situation the coherent mode is a good complement of the differential mode. This paper shows the result of a Matlab implementation of the 2 modes. The structure is as follows: in the first section of this paper, the differential mode of the physical layer of G3-PLC. In the next section, the coherent mode of G3-PLC will be explained. Section IV contains the evaluation by simulation.

## II. THE DIFFERENTIAL MODE OF G3-PLC

G3-PLC[2] is a standard developed by ERDF in France. This standard supports 3 modulations: DBPSK, DQPSK, D8PSK. A robust mode is included as well, this is a DBPSK signal repeated 4 times. G3-PLC transmits data between 35.9 and 90.6 kHz using an FFT-size of 256. With a sample frequency of 400 kHz, this gives a maximal throughput of 48kbit per second.

The header of G3-PLC is modulated with coherent BPSK. To detect and correct errors, the header is repeated 6 times and uses a (171,155) convolutional coding and a CRC5-coding. The preamble of each packet consists of 8 identical symbols and another 1.5 symbols which have the opposite sign. The phases of this preamble serve as the first reference for the PPDU.

The data itself is protected with a shortened (255,239)Reed-Solomon encoder or shortened (255,247)Reed-Solomon encoder for the robust mode. After the RS-encoder, an (171,155) convolutional encoder is placed. This encoder doubles the number of

bits and 6 zeroes are padded at the end of the bitstream to empty the encoder. After the encoder, the signal is repeated 1 or 4 times in normal or robust mode respectively. Finally, an interleaver mixes the whole packet such that bursts and frequency fading do not occur to the same bits. Interleaving this way gives protection against a bad frequency during multiple consecutive symbols and a burst error that corrupts a few consecutive symbols.

The mapping is done with a differential constellation. The reference of each symbol is the previous symbol. This gives G3-PLC the possibility to switch of carriers that suffer deep fading. This is done using a tone map. The tone map tells the G3-PLC receiver which frequencies carry data and which don't. After the inverse FFT, a cyclic prefix of 30 samples is added; finally for spectral forming, a raised cosine windowing function is used.

The block diagram of G3-PLC can be seen in Fig. 1.

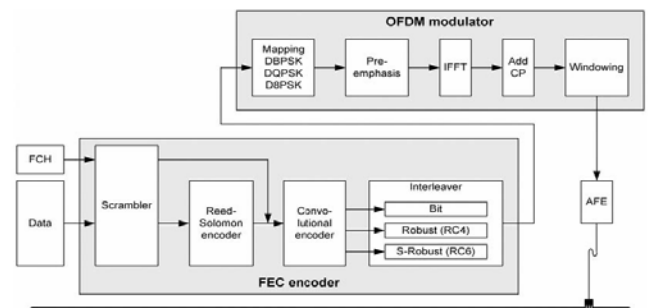


Fig. 1. The block diagram of G3[2].

## III. THE COHERENT MODE OF G3-PLC

The coherent mode supports 3 different modulations: BPSK, QPSK, 8PSK and even 16-QAM. As in the differential mode, the coherent mode has a robust mode. The robust mode copies the data 4 times. The coherent mode sends data between 35.9 and 90.6 kHz using a FFT-size of 256. With a sample frequency of 250 kHz, this give a maximal data rate of 48 kbs.

The previous paragraph showed the resemblances with the differential mode and also the preamble, FEC and the header are the same.

TABLE I CODEWORDS FOR EVERY STANDARD AND MODULATION

Standard and modulation	Codeword
differential G3-PLC ROBO	G30
differential G3-PLC DBPSK	G31
differential G3-PLC DQPSK	G32
differential G3-PLC D8PSK	G33
coherent G3-PLC ROBO	P10
coherent G3-PLC BPSK	P11
coherent G3-PLC QPSK	P12
coherent G3-PLC 8PSK	P13

There are also some differences that affect performance. The bits are mapped using a coherent modulation with the preamble as reference. This also enable the use of a tone map. 3 pilot tones are inserted in each OFDM-symbol for clock recovery and channel estimation. The position of the pilot tones has a fixed pattern. They change every symbol to another carrier to estimate all the frequencies. The way to use this pilot tones is not specified in the standard. Here as well, a raised cosine windowing function is applied.

The block diagram of the coherent mode is the same as the block diagram of the differential mode and is given in Fig. 1.

#### IV. SHE COHERENT MODE OF G3-PLC

The evaluation of the different standards is done using packets of 100 bytes, as in [4]. This value is chosen because every modulation can transport 100 bytes in its PPDU. The evaluation is also done with only data. The headers are not included, and thus every bit error in the packet, is a packet error. To make the legends smaller, a code shall be applied to each standard and modulation to make the figures more readable. The code is given in Table I. In this work, 5 scenarios are created to compare the performance of the 3 standards: IV-A, IV-B, IV-C, IV-D and IV-E. IV-A, IV-B and IV-C were done in [4] to compare the differential mode with the physical layer of PRIME. IV-D and IV-E were added here to specifically test the performance of the coherent mode of PLC-G3. Each test uses the same sequence: first, the data is generated, then this data is coded. The coded data is then filtered with a channel impulse response and noise is added to this line. Subsequently, the resulting signal is decoded and the bits out of the decoder are compared with the initial bits. When the channel impulse response is not given, a unity impulse response is used.

##### A. PLC Background Noise

In [5], a model to simulate power line noise is given. They showed the noise on a power line in the CENELEC A-band is cyclostationary with the frequency of the grid. The proposed noise model is used to generate noise for the simulated power line.

In Fig. 2, the PER is visualized. The coherent mode has a better PER, because of the coherent modulation, which is less sensitive to error propagation. When using a differential mode, noise is added in both the reference

symbol and the symbol itself, and an error occurs if at least one of the two is affected by noise. This results in a higher PER for the differential mode for the same SNR.

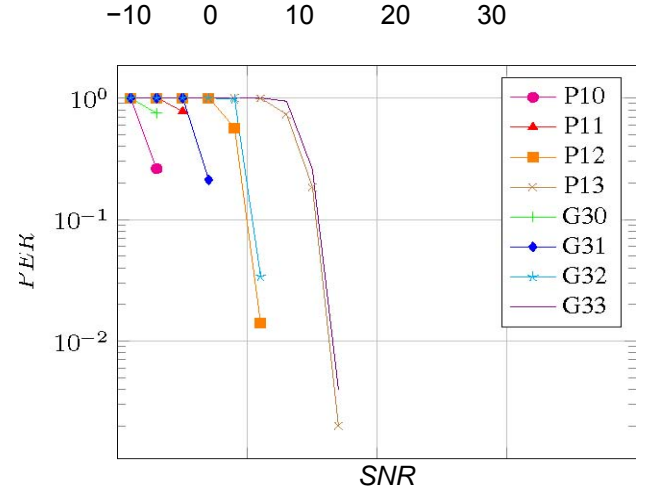


Fig. 2. For power lines with only power line noise, the coherent mode performs better than the differential mode.

##### B. Frequency Selective Channels

Channels in power line include deep fades for certain frequencies. [1] proposes a channel frequency response based on [6]. To change the SNR, white gaussian noise is added.

The PER for this test can be seen in Fig. 3. As this test used 500 different channels, there are channels that have deeper fading for certain frequencies than others. The differential mode performs better for higher SNR than the coherent mode because the pilot tones add wrong information when they are situated in a strongly attenuated frequency band. On the other hand, the coherent mode performs better for lower SNR because it performs better when there are no frequencies that are too strongly attenuated.

##### C. Narrowband Disturber

FSK and S-FSK are two very narrowband modulations that are already in use in the CENELEC A-band. This NB-PLC acts as noise source in this test. To model this noise, a sine with a power 10 dB weaker than the power of the signal is applied on the signal. To change the SNR, additive white Gaussian noise is added.

Fig. 4 shows the PER when the two modes of G3-PLC don't use their tone map. The differential mode performs better than the coherent mode, because the pilot tones in the frequency band with the sine generate false channel estimations. If these sub-carriers are turned off by the tone map, the communication becomes more reliable. Fig. 5 compares DQPSK for both modes with and without tone map.

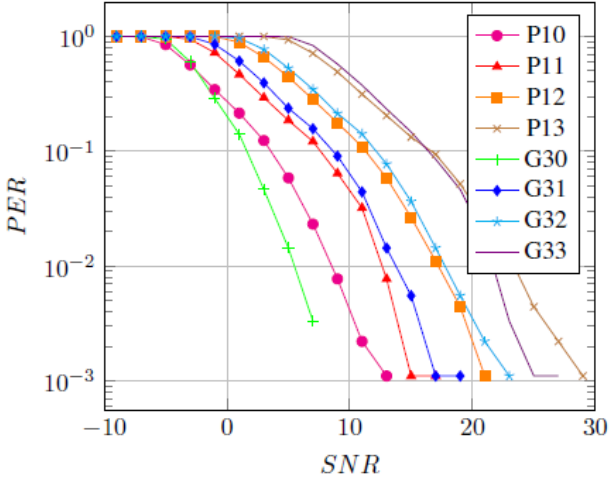


Fig. 3. The differential mode performs better in this scenario in most of the cases, because pilot tones in deeply faded frequencies give very bad estimations

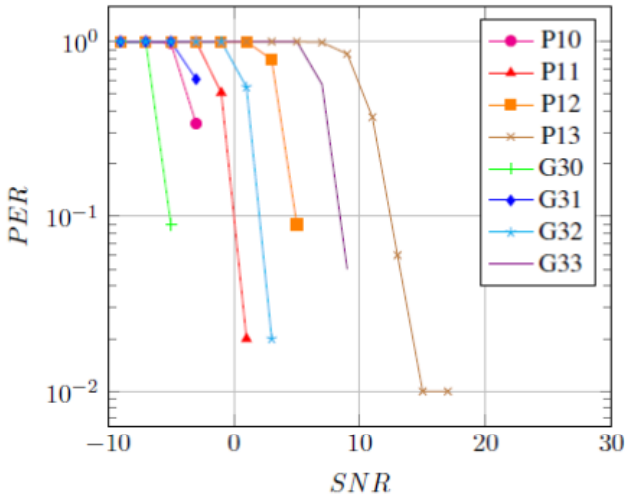


Fig. 4. When the narrowband disturber is applied, the differential mode performs better.

#### D. Fast Time-Varying Channels

When plugging in a device, the impedance of a PLC network can change very fast [3] and so does the transfer function. To model this, a Dirac impulse with an amplitude of one and a delayed and attenuated Dirac impulse are used to model the changing channel. After 2000 samples ( $8^{\text{th}}$  symbol), the channel changes.

Fig. 6 shows that when a channel suddenly changes, the differential mode performs better than the coherent mode. The coherent mode is implemented to estimate the channel based on the pilot tones and interpolate the results. So when the channel changes, it takes 6 symbols to converge to the new channel, because it takes 6 symbols for the pilot tones to reach the same carrier. 5 symbols are

lost, but these 5 symbols can be corrected if there is enough redundancy. So for DQPSK, DBPSK and ROBO, the FEC can correct the errors, but when using D8PSK, there are too many false bits. The differential mode on the other hand loses just 2 symbols, but its FEC can remove this error.

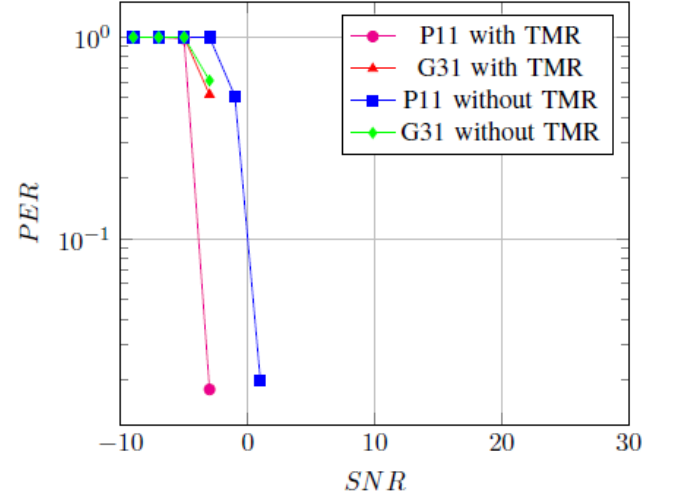


Fig. 5. Without the corrupted carriers, they have both a performance equal channel to a white noise scenario.

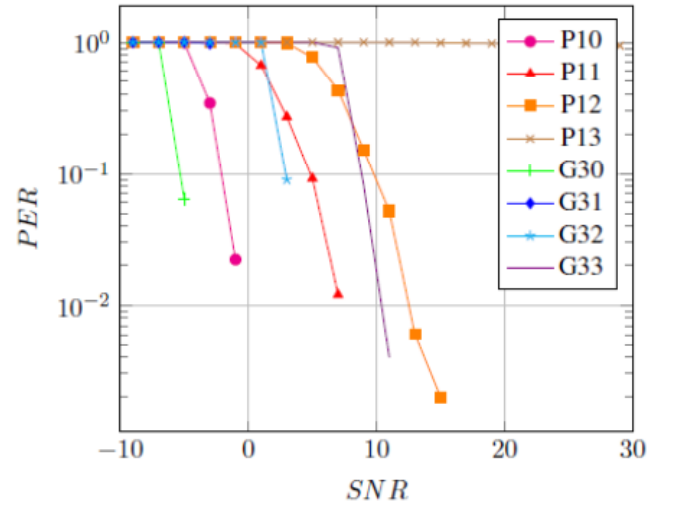


Fig. 6. For a fast time-varying channel, the differential mode performs better because the coherent mode loses more symbols due to an incorrect channel estimation.

#### E. Slowly Time-Varying Channels

Slowly varying channels are fast time-varying varying channels with only small changes due to changes in the topology, and are modeled using the same transfer functions as in subsection IV-D but linearly interpolated. With the linear interpolation,

every symbol gets its own transfer function and is filtered with it.

Fig. 7 shows the PER for a slowly varying channel. Because there are only small variations, Both modes in G3PLC have no problem solving these small changes.

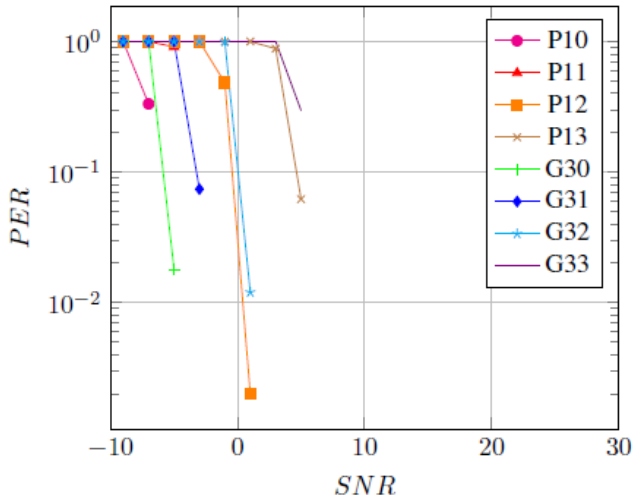


Fig. 7. With a correct channel estimation, the coherent mode performs better than the differential mode.

## V. CONCLUSION

The novel coherent mode of G3-PLC is a good extension of the existing differential mode in static environments or varying situations with only small variations. When the coherent mode is able to correctly identify the channel, it performs better than the differential mode if the bad sub-carriers are excluded. The channel estimation and excluded sub-carriers are therefore important parameters. But, on the other hand, the complexity of this coherent mode is higher and the highest possible data rate is lower.

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